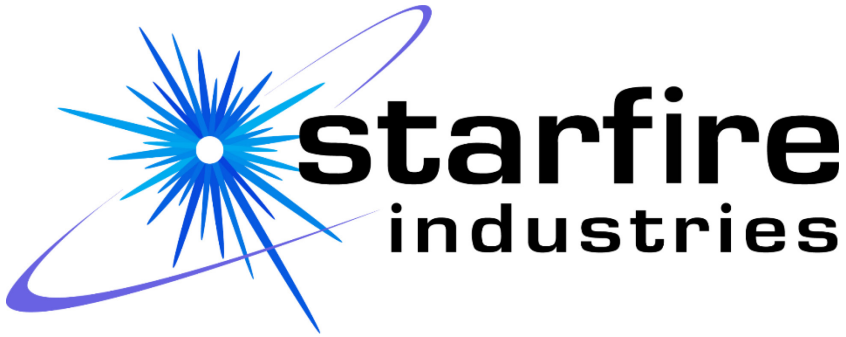
Am-Be Replacement With Tunable Neutron Spectra For Downhole Applications



BRIAN E. JURCZYK

WWW.STARFIREINDUSTRIES.COM

DEC 16-17, 2020 VIRTUAL MEETING

THE NATIONAL ACADEMIES OF SCIENCE, ENGINEERING & MEDICINE

Motivation…

^{241}Am sources pose radiological dispersal device (aka "dirty bomb") security risks

- 5-10k Am-Be sources (4-16Ci) in circulation; many in the back of borehole logging trucks across the country

Governments and regulatory bodies are looking for alternatives, e.g. ^{252}Cf, D-T, NMR, etc.

- Several scoping studies were released (i.e. LLNL-TR-679101) and a few exploratory papers published

D-T neutron generators were obvious starting point... but small-medium scale well loggers pushed back

- Tritium, dual-use export/location controlled, neutron energy and log response is very different, cost!

Also, many environmental, water, geotechnical & solution mining wells cannot use Am-Be due to radioactive source liability! There is a need.

To encourage small/medium well loggers to switch, a replacement technology must address:

- **Am-Be Log Comparison (75+ years of data/experience)**

And

- Total Cost (Upfront + Recurring + End Of Life)
- Regulatory Burden (Lower or Push)
- Provide Additional $ Data (Statistics, Pulsed)

Review: Basic Neutron Tool For Well Logging

Compensated Logger With Near/Far Detector

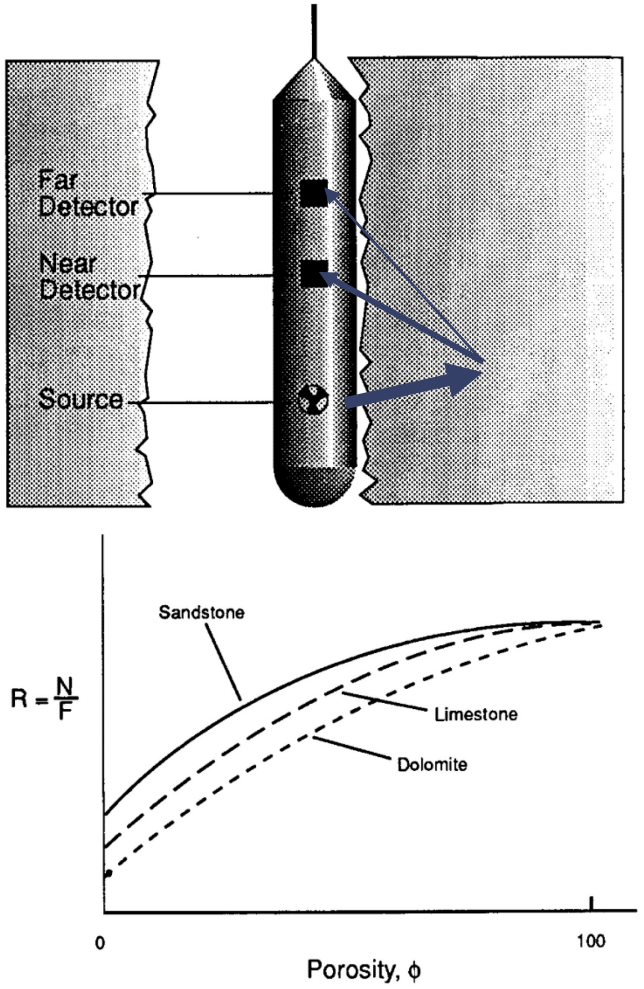


Figure 1. The neutron porosity tool and the ratio-to-porosity transform.

Neutrons Pass Through Materials Easily

Neutrons Enter, Some Return Depending On Lithology, Porosity %, Gas/Water/Oil/Minerals

Neutrons Slow Down Through Elastic Scatter In The Formation

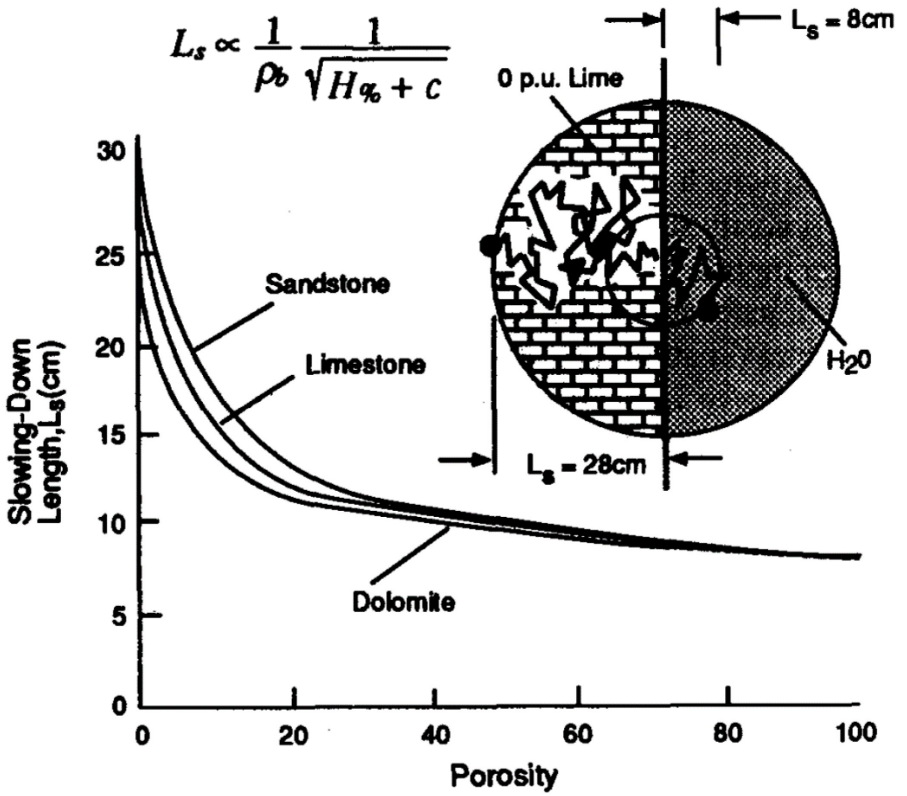


Figure 2. Neutron slowing-down as a random walk. The curves show computations of slowing-down length as a function of porosity for three common rock types.

D. Ellis, Schlumberger, IEEE Trans. Nuc. Sci., 37, 2, Apr 1990

Review: The Gold Standard: (L_s x ρ Product)

The measurement of the spatial (NEAR/FAR) distribution characterizes the moderating efficiency (L_s) of the formation

The ratio of the NEAR/FAR neutron detectors can be transformed into porosity combined with formation density (ρ) calculated from gamma-rays (e.g. Cs-137)

The L_s x ρ Product is golden since nearly all geomaterials follow a continuous curve

- Deviations from this line indicate presence of hydrocarbons, salt, loose compaction, brine, etc.
- **Accuracy of 1% p.u. = equal $MM per oil well**

Neutron (Am-Be) and gamma (Cs-137) logging give detailed information on lithology, presence of gas, and factors that affect apparent porosity.

D. Ellis, Schlumberger, IEEE Trans. Nuc. Sci., 37, 2, Apr 1990

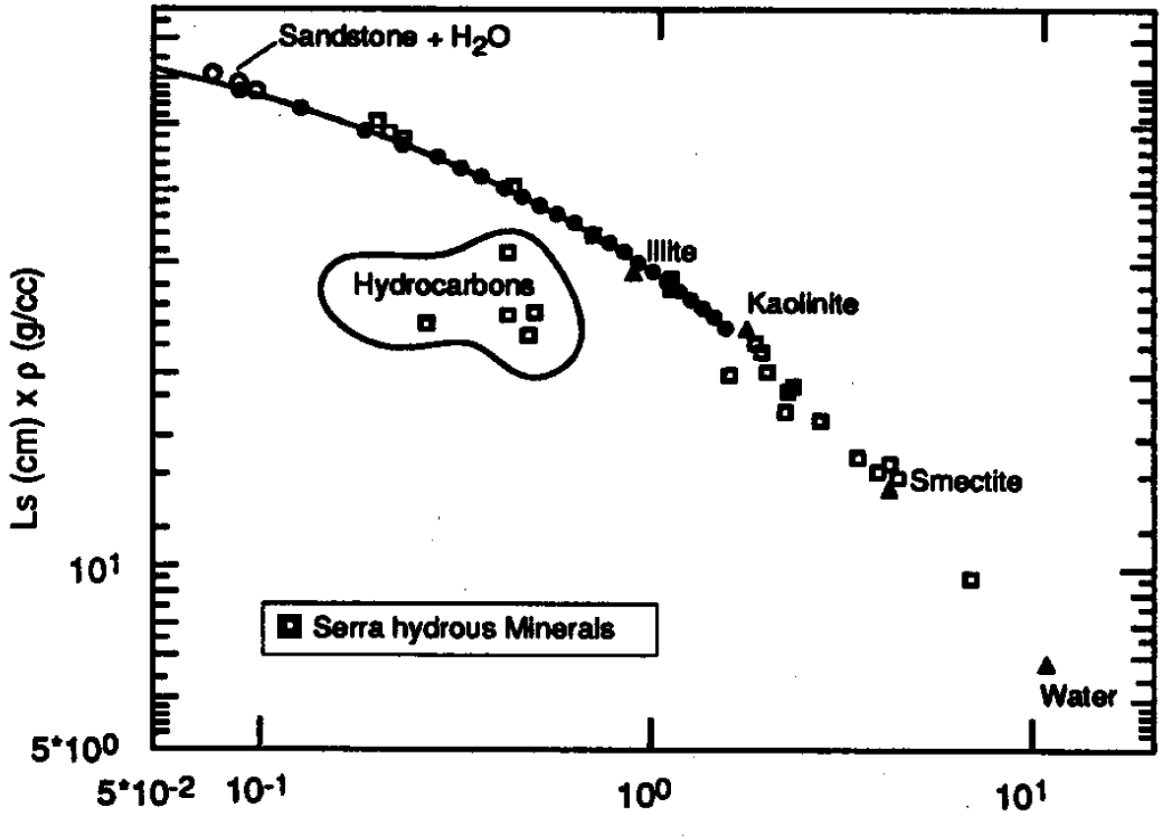
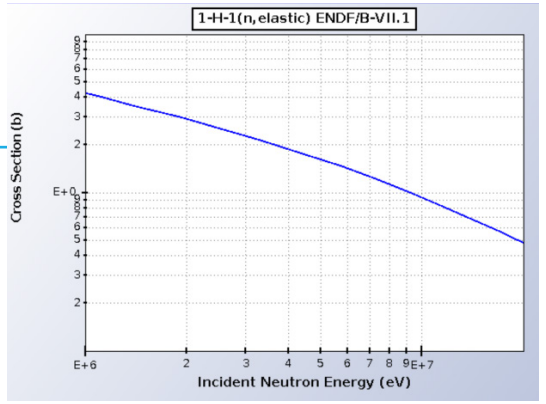
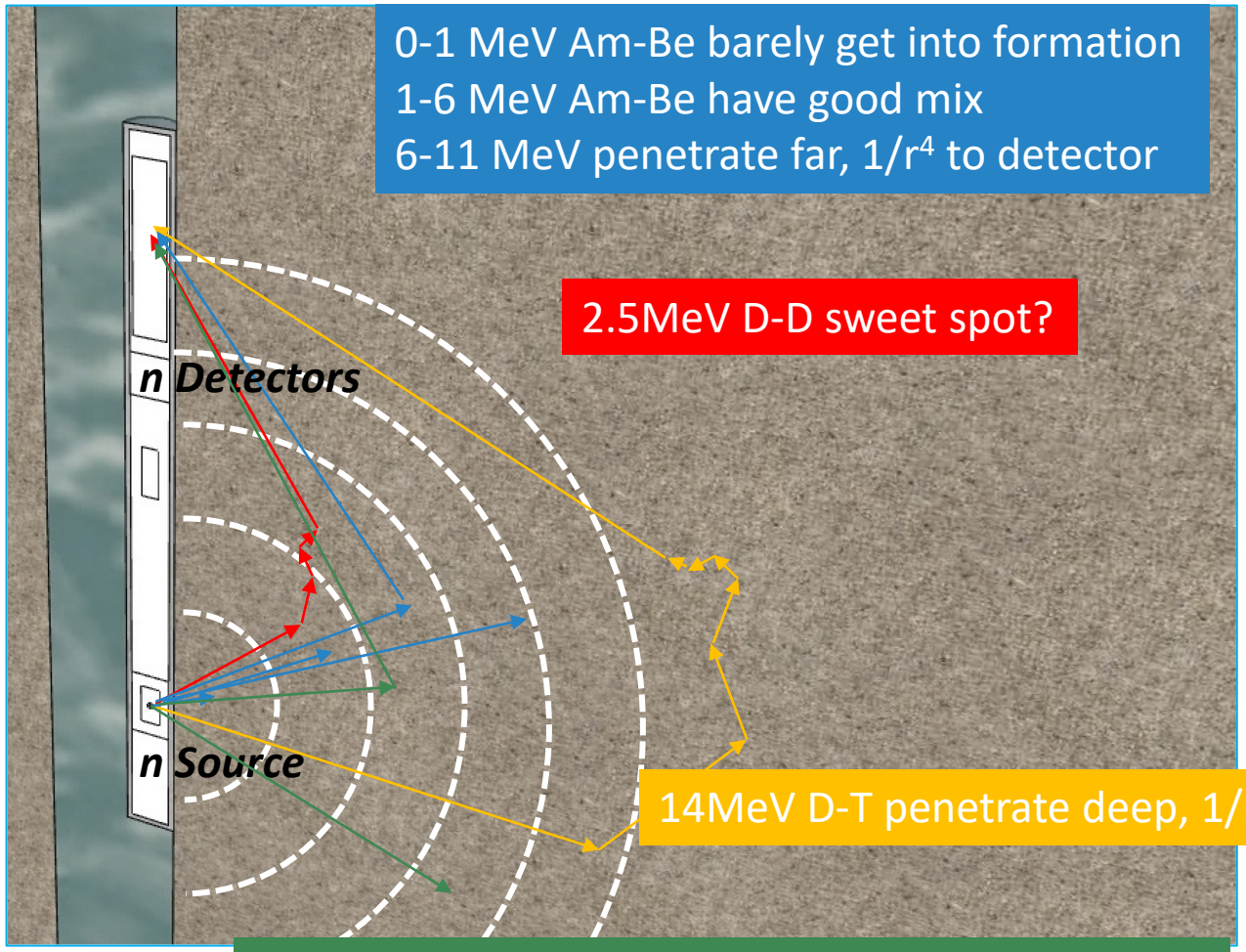
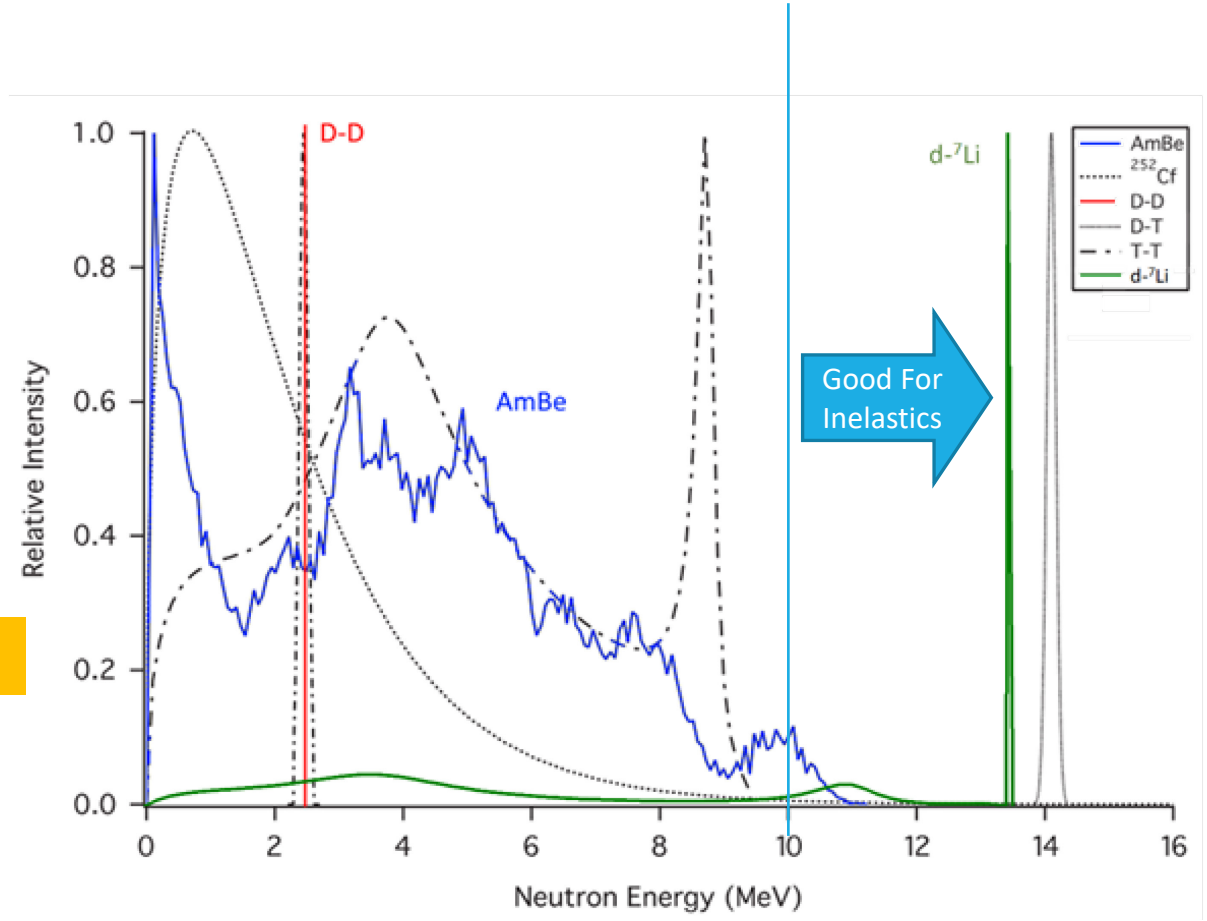


Figure 4. The product of density and computed slowing-down length as a function of the hydrogen weight fraction for water-filled sandstone and a number of clay minerals.

Neutron Energy Effects In Formation







Starfire's Staged Approach (Non-Radioactive)

Stage 1: Develop Neutron Porosity Tool Using the **D-D Fusion Reaction**

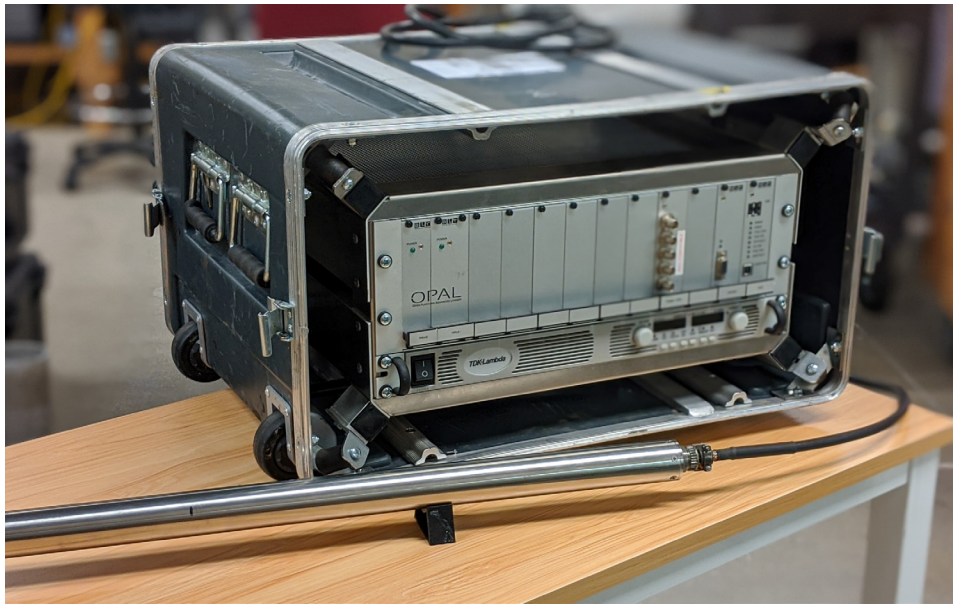
- Replace Am-Be In Shallow-Well Neutron Porosity and PGNAA Applications (water, environmental, mining, geotechnical)

Stage 2: Develop Tuned Neutron Energy Spectra Using the **D-Li Fusion Reaction**

- Direct Am-Be Replacement In Neutron Porosity (+ oil/gas)
- Full Gamma Spectroscopy (+ inelastic C/O)
- Basic Gamma Density (poor Cs-137 replacement)

Stage 3: Scale Technology For Deep-Well and Logging-While-Drilling Applications

- Enable D-D/D-Li non-radioactive solution for well services companies for very large section of market



nGen®-100 + MSI® QL40 + Open Platform Advanced Logging

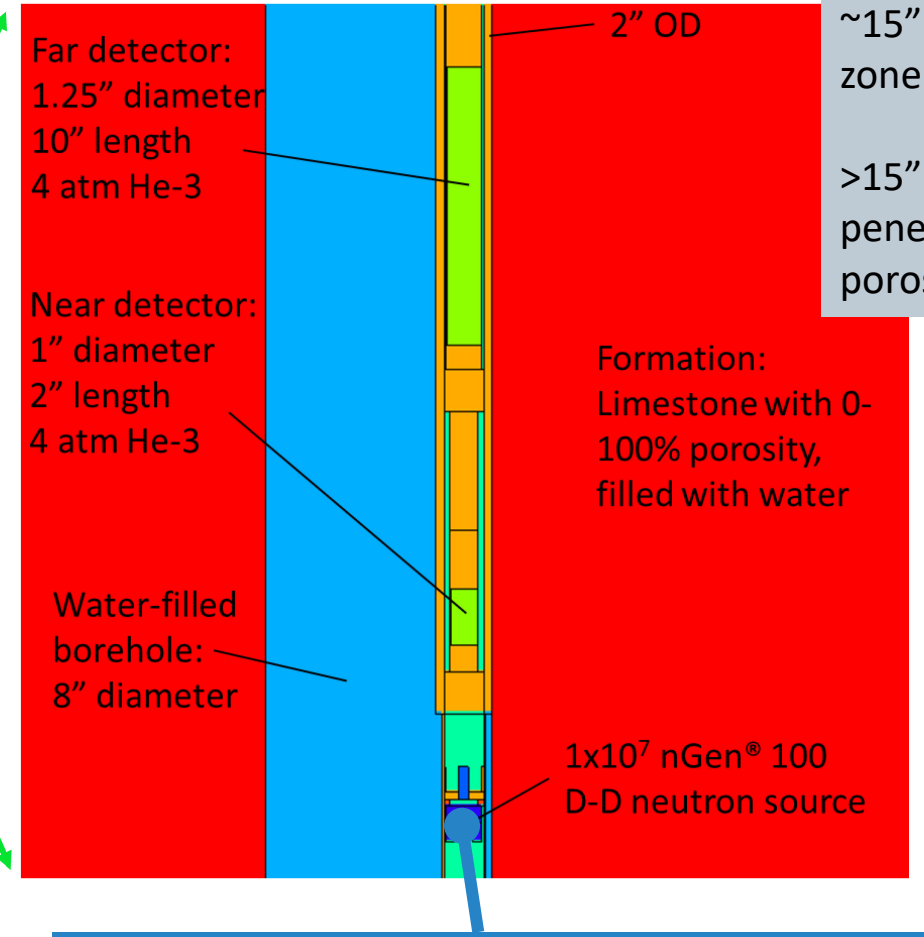
Stage 1: Technical Approach

nGen® technology enables grounded targets for neutron emission
- Optimize NEAR/FAR formation response for ideal 2.45MeV energy with appropriate detectors

Integrate into Mt. Sopris QL40 stackable downhole probe line hardware
- Adapt software/control for Open Platform for Advanced Logging and WellCAD user interface

Deploy fieldable units for test well characterization with USGS, ISGS and other first mover customers
- Slimline 2” OD tool can be decentralized against wellbore wall

Extendable for PGNAA gamma-density and spectral information



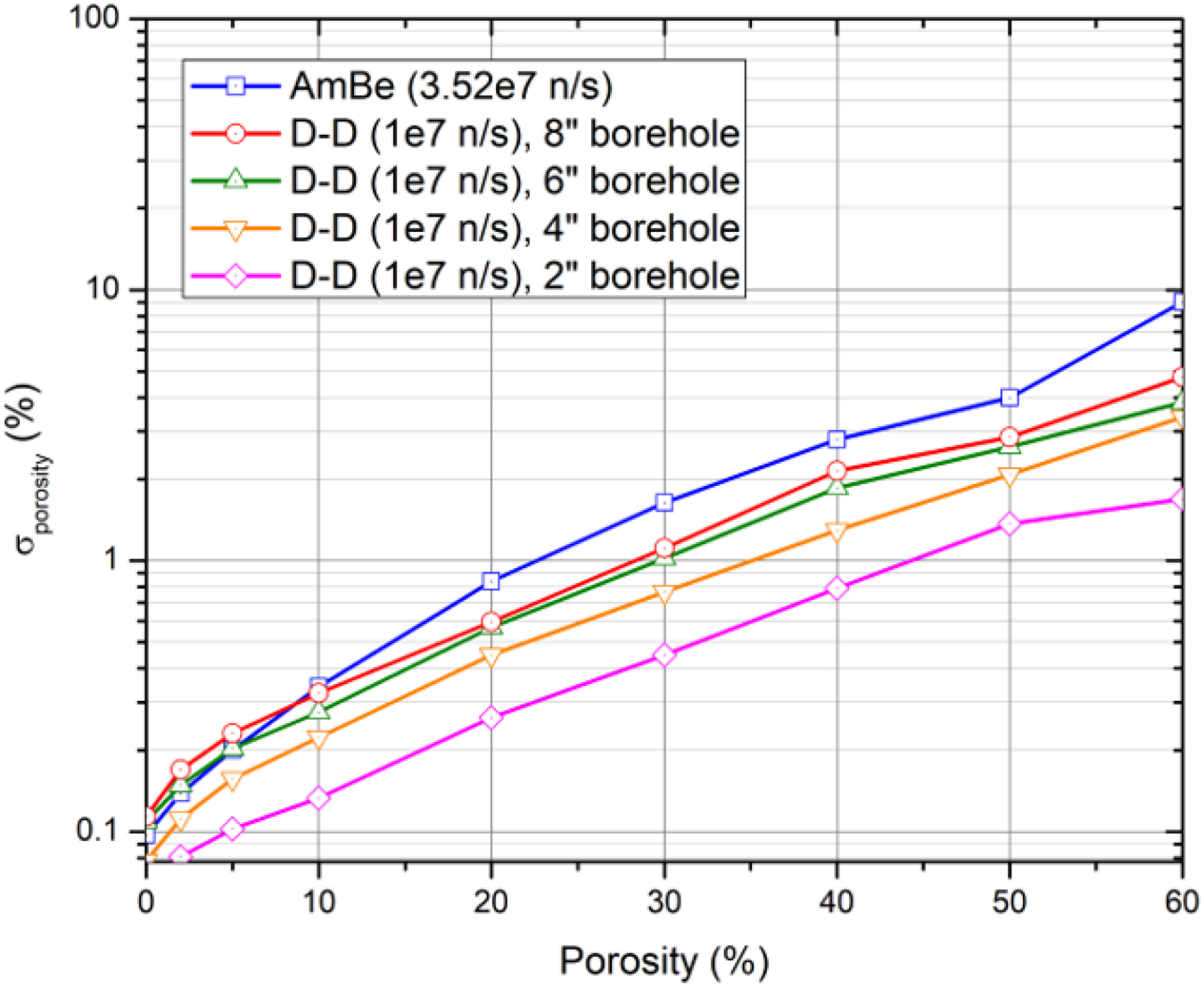
~15” interrogation zone length

>15” depth of penetration for 0% porosity formation

Starfire’s nGen®-100 grounded end target allows close placement of NEAR/FAR detectors optimized for D-D energy

**older tech using –HV biased targets could not do this*

Results for D-D Neutron Porosity Tool: Borehole D



Comparing 8” Bore, Almost Identical Profile Except At Very Low Porosity 0-5%

NEAR detector shielding improves this

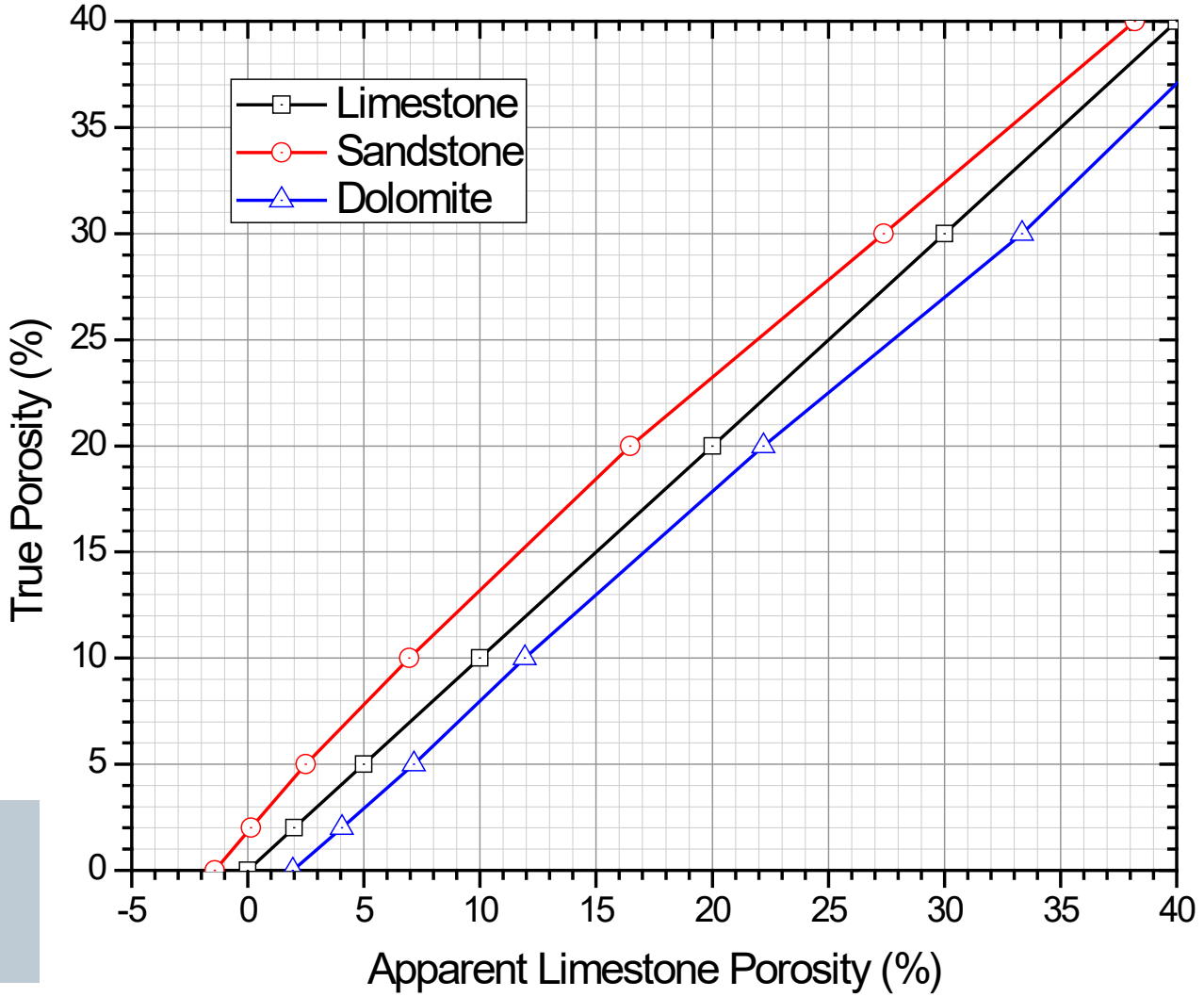
Moving detectors CLOSER to the GROUNDED emission point = **better statistics @ fraction of source strength… do more with less!**

Error in porosity decreases for smaller boreholes as expected

D-D greater sensitivity to porosity from 2.45 MeV neutrons vs. Am-Be spectrum 0-11 MeV

Lithology Correction = Good!

Correction chart for obtaining porosity values for lithologies other than limestone



Similar to same chart for Am-Be
Addresses major hurdle!

Correction fed into WellCAD

This excellent result lowers the barrier to switch from Am-Be

Dr. Paul Glover, Petrophysics MSc Course Notes

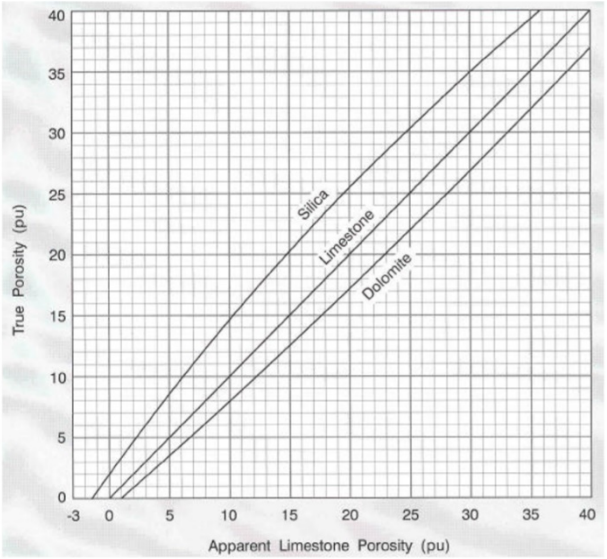
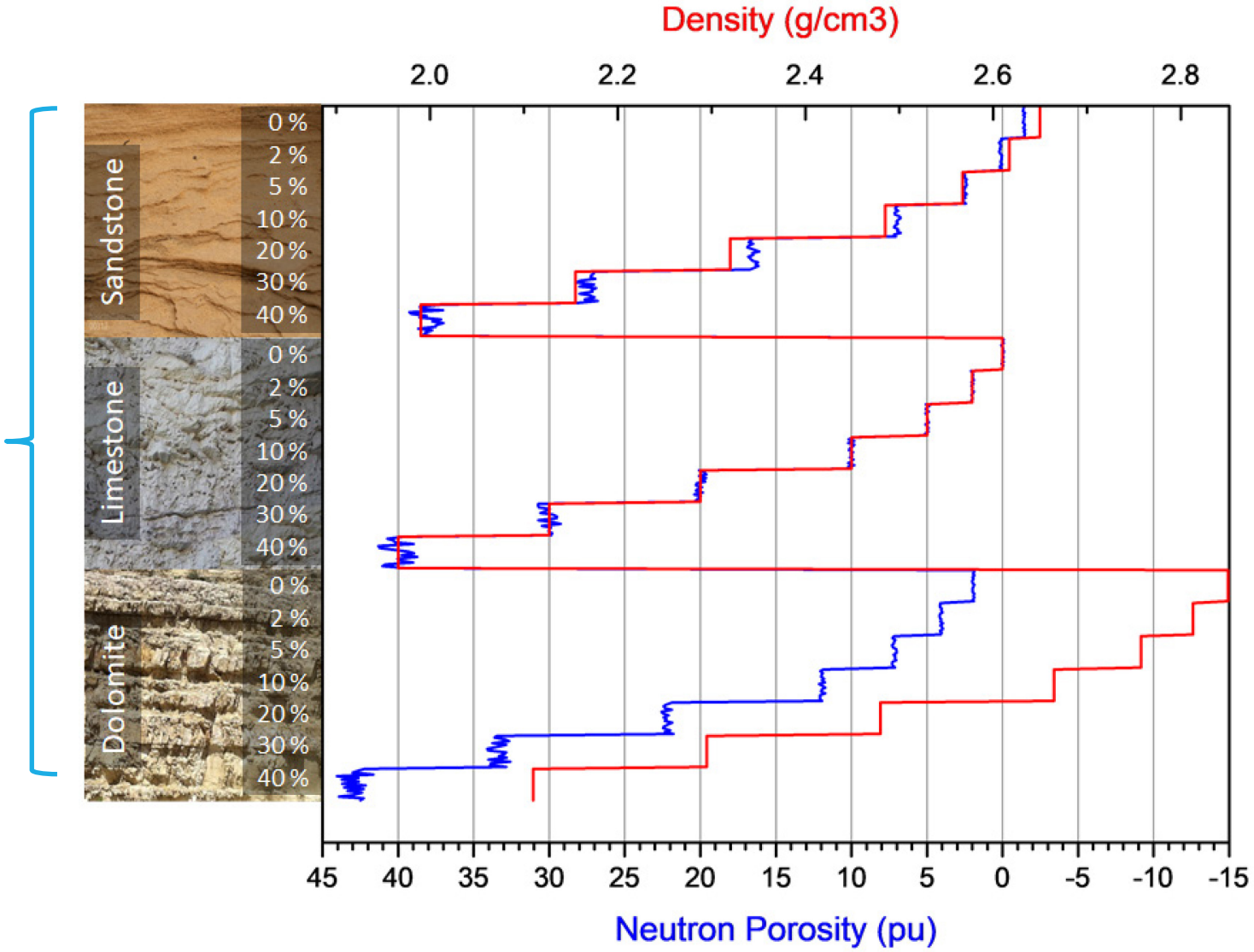


Figure 15.8 Correction chart for obtaining porosity values for lithologies other than limestone.

Simulated Log Response = Good!

Varying lithologies and porosities



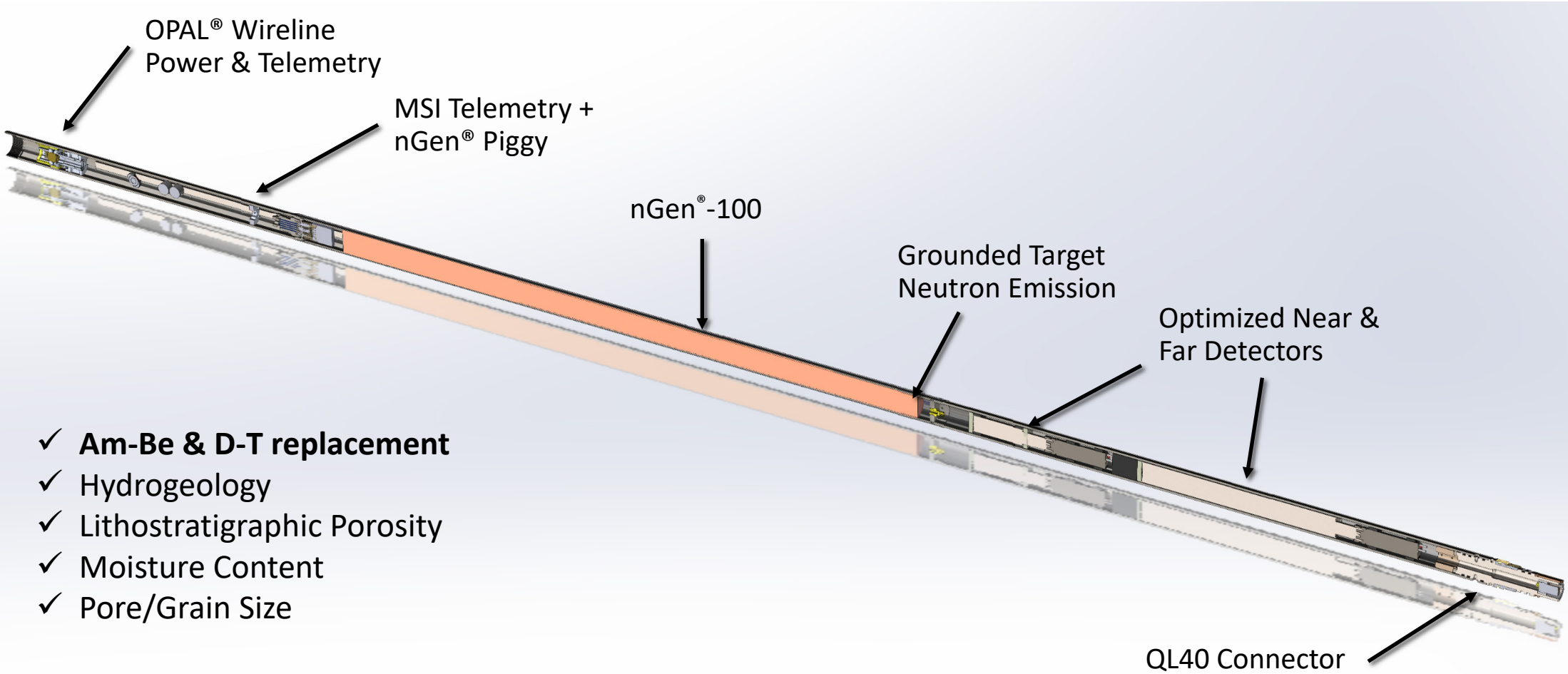
Lithology can be mapped with neutron porosity and gamma density

L_s x ρ still applies

Correction factors generated similar to Am-Be

This excellent result lowers the barrier to switch from Am-Be

QL40-nGen®-CNL Compensated Neutron Logger



- ✓ **Am-Be & D-T replacement**
- ✓ Hydrogeology
- ✓ Lithostratigraphic Porosity
- ✓ Moisture Content
- ✓ Pore/Grain Size

MOUNT SOPRIS INSTRUMENTS

starfire industries

ALT Advanced Logic Technology

SBIR Program Outcomes

Addresses a critical market gap for non-oil/gas applications in **water**, **mining**, environmental well management

- Immediate product solution for low-security downhole users (approx. 50% market)

Establishing D-D neutrons as a viable Am-Be replacement for early adopters

- Eliminates radiochemical handling for this low-security market

Extendable for traditional oil/gas wireline and surface PGNAA applications

- Excellent limestone porosity (% p.u.) response compared to 16Ci Am-Be at 1/3 source strength

Partnership with Mt. Sopris Instruments (Denver, CO) and worldwide end-users/tool developers

- User-friendly compensated neutron porosity logger using widely-used WellCAD software & QL40 tooling

Pathway for Stage 2: D-Li neutrons established

- **Investment in rugged, ultra-compact HV generation**

"Approximately 800,000 water boreholes are drilled in the U.S. annually. The construction of these vitally needed water supply systems involves the use of more than 18,000 drilling rigs by an estimated 8,100 groundwater contracting firms."

Thank You

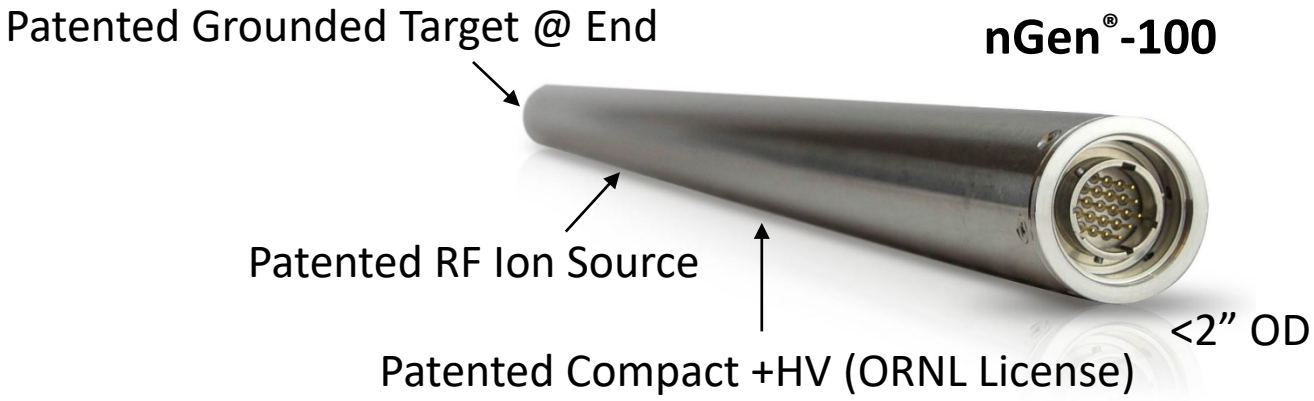
FOR MORE INFORMATION PLEASE CONTACT:

WWW.STARFIREINDUSTRIES.COM

About Us…

Starfire Industries located in Champaign, IL USA (near *University of Illinois*)

- ~30 employees, including 6 PhDs
- 14,000 ft^2 engineering, lab/test and production space
- Complete vertical integration from R&D, manufacturing, applications testing and support
- Making neutron generators and pulsed plasma sources for 10+ years!



Product Matrix:

- **nGen® portable neutron generators**
- Centurion® transportable MeV particle accelerators
- IMPULSE® pulsed power modules for sputtering
- RADION™ plasma sources for ALD, PECVD & etching

This Talk: Neutron Generators for Well Logging